# Research on Control Method of VSC based DC grid with Weak AC system integrated

*YU Yong-sheng*, JIA Jian-hua*, Feng Yan-hui†, Qiu Ying-ning†, WU Sheng-zhi*, XIAO Jian-chao*, ZOU Zhi-wen**

*State Grid Tianjin Jizhou Electric Power Supply Company

†College of energy and power engineering, Nanjing University of Science and Technology

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## Abstract

Scenario of Passive grid connecting two VSC-HVDC transmission systems has been investigated in this paper. A control method with hierarchy is proposed. VSCs have been grouped into a hierarchy of various categories. Distance which denotes the number of connections with strong grid of VSC stations is used to define the hierarchy used in this paper. Different control methods are used in different categories to regulate different variables. This method can be used in DC grids with many VSCs grouped into a hierarchy of various categories. This paper presents a multilayer DC system with a passive AC grid inside the DC grid. The control principle of VSCs connected with the passive grid is investigated. The AC voltage control and active power control is assigned to different VSC based on its power flow in the inside passive AC grid. Also a DC voltage control is integrated in the hierarchy control system to improve the dynamic instability.

## 1 Introduction

With wide applications of power electronics, high voltage DC transmission(HVDC) and DC grids has been a necessary complement to AC grid. Dozens of HVDCs have been running many years in China, which transfers large amounts of superfluous electricity from central and western regions to load center in eastern area. Furthermore, HVDC, together with HVAC(High Voltage Alternating Current), is delivering electricity generated from renewable energy (such as wind energy and solar energy) to East China power grid and North China power grid. Hydroelectricity is also transfer from Southwest China to China Southern power grid by HVDC.

Because of the space limitation, electricity is transferred by cable in urban power distribution network. As the distance increasing, DC(Direct Current) transmission is becoming cheaper than AC(Alternating Current) transmission. Also DC transmission only has two lines, which save a lot of space in urban area[1]. VSC-HVDC (Voltage Source Converter Based High Voltage Direct Current) has the advantage of integrating and coordinating wind – generated electricity and solar power generation because its independent and decoupled control of active power and reactive power[2]. Accordingly, DC grid can be used in urban energy internet.

DC grid must be connected to AC grid through several converter stations for a majority of loads in electric power system are used AC power. The connection between VSC-HVDC and AC grid has been discussed at length. An improved feed-forward control is proposed in [3], which based on stability analysis and small signal analysis. The performance of reactive power has been improved by using this control, resulting in stability increasing. In [4], the author proposes to use an imaginary bus in the connection between the VSC and very weak grid. At the imaginary bus, the connection can be considered connecting to a strong bus. Then, the controller can be designed as the VSC is connecting to strong grid. Reference [5] suggests modifying the current limit tactic and uses frequency hysteresis control in the connection between the VSC and passive grid to increase transient AC voltage stability. DC cable model has been discussed in [6]. It is shown that VSC-HVDC model containing long distance transmission or large impedance in cable can meet the demands of precision by using one $\pi$ section model in DC cable. The VSCs in [6] have been classified as DC voltage control station and active power control station. Reference [7] investigates the DC system had bad impact on the system when the SCR is low. Considering the adjustment of control variables, reference [8] builds a model of VSC-HVDC supplying power to island system which is a weak grid. Based on [8], VSC-HVDC connecting two weak systems is built in [9]. By analyzing the dynamic braking resistor, a novel coordinated control strategy is proposed in [10]. Braking resistor is not only used in fault conditions to consuming extra energy that will damage the equipment in power grid, but also used in condition of start-up to restrain the power and voltage overshoot. The correlations of active power, reactive power, q-axis and d-axis are discussed in [11].

A passive grid connecting two VSCs has been investigated in this paper and a hierarchical for DC grid is proposed.

## 2 Methodology

### 2.1 Control of DC grid

DC grid can be divided into two groups according to whether the DC grid has an AC grid in it. One of the groups is that all the VSCs have been connected through DC transmission line, which, on the other hand, means there is no AC grid within the DC grid. This kind of DC grid can be formed by extending point to point VSC-HVDC[12], also known as multi-terminal VSC-HVDC. The other group describes the condition AC grid existing inside

## V. CONCLUSION

In this paper, the regional power grid's acceptance capacity for wind power is analyzed. From the research point of view, the power load level and power grid peak shaving ability are the main factors affecting wind power acceptance level. In order to improve the wind power acceptance level, in some cases wind power curtailment is necessary. Improving the power regulation capability between regional grids should be the fundamental way to improve the Wind power acceptance level.

In the calculation of wind power acceptance level in this paper, the capacity reliability of intermittent power supply needs to use the reasonable installed capacity. The reasonable installed capacity not only depends on the intermittent resource characteristics, but also depends on the grid size, power supply structure and load levels and many other factors, which is a complex problem.

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**Weiguo Yan** was born in 1962. He has been engaged in power dispatching operation, relay protection technology and management, power grid production operation management, etc. He is currently the deputy general manager of State Grid Tianjin Electric Power Company and has rich experience in power grid operation management.

AC grid. There are differences between these two control modes. As the control of VSCs in 2nd layer, there must be one station to be the balance station to make the inflow and outflow power equal. The active power injection and extraction will have effect on the stability of the system.

The DC voltage control is used in 1st layer control to regulate the DC voltage in DC line. A constant DC voltage is a requirement for maintain the power transferring stably from 1st layer control VSC to 2nd layer control VSC. If the 1st layer control does not function well, the 1st layer control will affect the 2nd layer control. The 2nd layer control is used to control the AC voltage and active power in the weak AC system to maintain the weak AC grid steady.

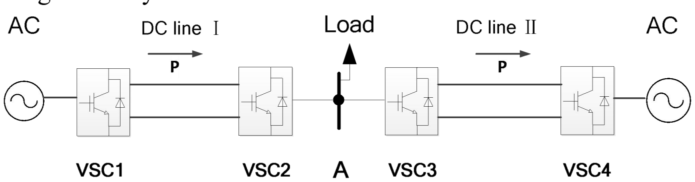


Fig. 3 Diagram of direction of power flow in VSC based DC grid

Based on the model simulated in this paper, VSC injecting power into the weak grid is called IP-VSC(VSC that inject power) and VSC extracting power from the weak grid is called EP-VSC(VSC that extract power). The focus of this paper is the IP-VSC and EP-VSC connecting to the weak AC grid, also the 2nd layer controlling VSC.

In weak AC system, the variables controlled by IP-VSC and EP-VSC should be selected to avoid their bad effect on the stability and dynamic response of the whole system. The control strategy of "IP-VSC controlling voltage and EP-VSC controlling active power " and "IP-VSC controlling active power and EP-VSC controlling voltage" is compared in this paper. "IP-VSC controlling voltage and EP-VSC controlling active power" means that the IP-VSC controls AC voltage of weak AC grid and the EP-VSC controls the active power transferred by the EP-VSC, and vice versa.

Fig.4 shows the model adopting "IP-VSC controlling active power and EP-VSC controlling voltage". Considering there is little load in weak AC grid and the system need to have the ability of black start-up, there need to be a phase angle control in VSC2 or VSC3. Also, the firing frequency should be set to maintain the fundamental wave. Thus, the weak AC grid can get a stable reference angle and frequency.

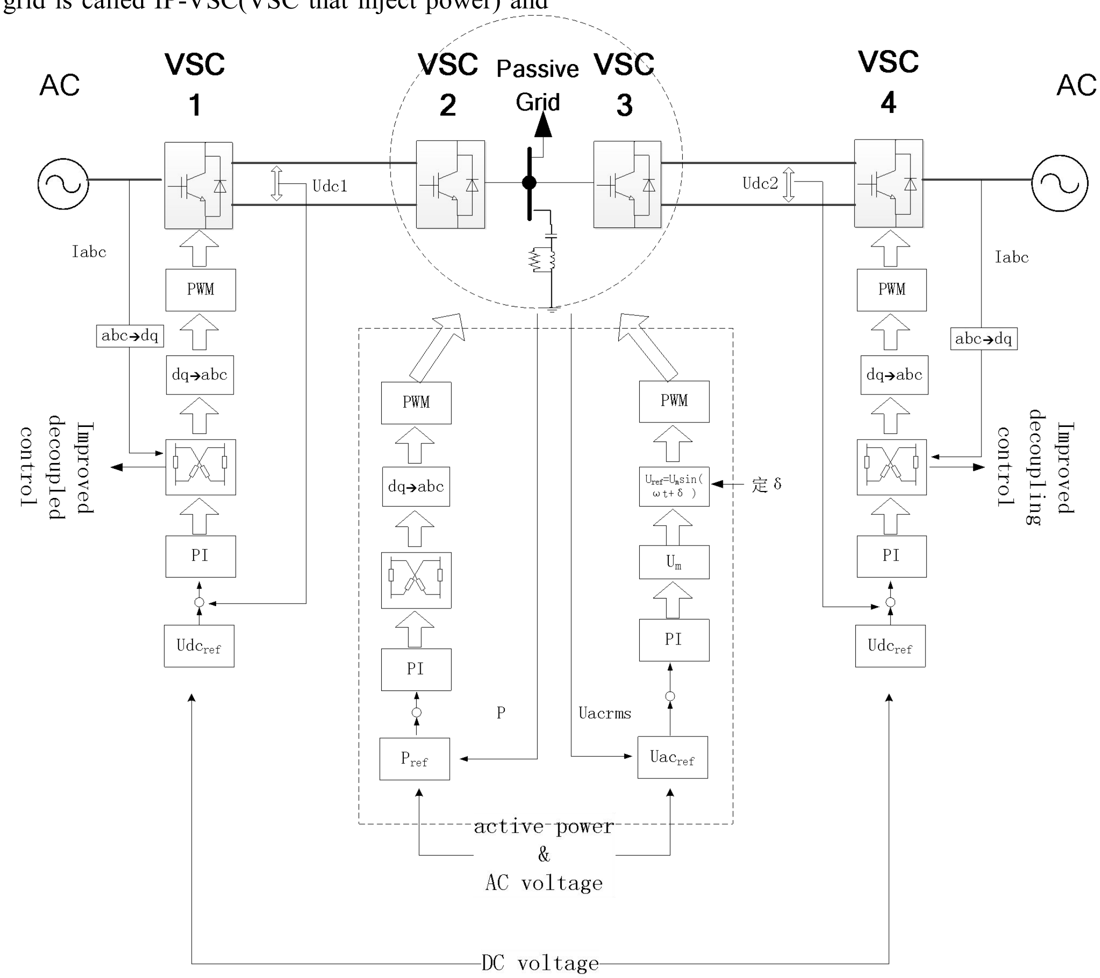


Fig. 4 Diagram of the control of the whole VSC based DC grid

In 2nd layer control, the VSC2 supply power to VSC3 and load in passive grid. A disturbance will make the PLL (phase lock loop) unstable and will lead to the frequency and phase angle deriving from PLL will fluctuate. So the power transmission will be affected[4]. In the meantime, the instability of AC voltage will appear and it will make the PLL dynamic worse. It is a vicious circle. To avoid the vicious circle, A given phase angle is used in 2nd layer control. Even though the power transferred by this VSC cannot be controlled, the stability of weak system is assured. So this VSC is used as balancing VSC.

In 1st layer control, a stable DC voltage is needed, so an overvoltage control is used in each VSC DC side. The overvoltage control uses IGBTs in series with a consuming resistance. The IGBT and the consuming resistance parallels with the DC capacitance (fig.5). When the DC voltage exceeds the 1.1$U_n$ ($U_n$ is the rated voltage), the overvoltage control is triggered. There is current flowing past the IGBT and consuming resistance. The capacitance is protected from breakdown and the overshoot of DC voltage is controlled. The reference value of the over voltage control should be adjusted based on the DC voltage control of the 1st layer VSCs.

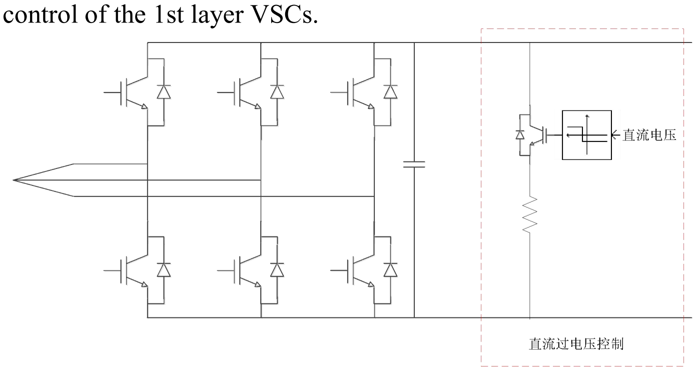


Fig. 5 Diagram of overvoltage control

## 3 Results & Discussion

Using the control scheme shown in fig.4, an improved feed-forward double loop decouple control[14] is used in VSC control. DC voltage control is adopted in outer-loop control in 1st layer control. AC voltage control with a fixed phase angle is used in one of the 2nd layer control VSCs and active power control is used in the other VSC of the 2nd layer control.

In the simulation, “IP-VSC controlling voltage and EP-VSC controlling active power” is compared with “IP-VSC controlling active power and EP-VSC controlling voltage”. “IP-VSC controlling voltage and EP-VSC controlling active power” is called “1st control strategy” for simplicity and “IP-VSC controlling active power and EP-VSC controlling voltage” is called “2nd control strategy”.

From fig.6 to fig.11, DC grid with 4 VSCs using hierarchical control can function well and power transfer steadily.

Comparing fig.6 and fig.7, for the item of AC voltage in weak AC grid, the 1st control strategy needs 0.9s to stabilize the AC voltage, however, 2nd control strategy needs 0.5s to stabilize the AC voltage. Considering the ability of AC voltage stabilization, situation that the IP-VSC adopts active power control is better than that the IP-VSC adopts AC voltage control. So it is better to use EP-VSC as AC voltage control station in 2nd layer control. Furthermore, the overshoot of active power transferring from VSC1 to VSC4 is smaller in 2nd control strategy and 2nd control strategy has less oscillation in the start-up.

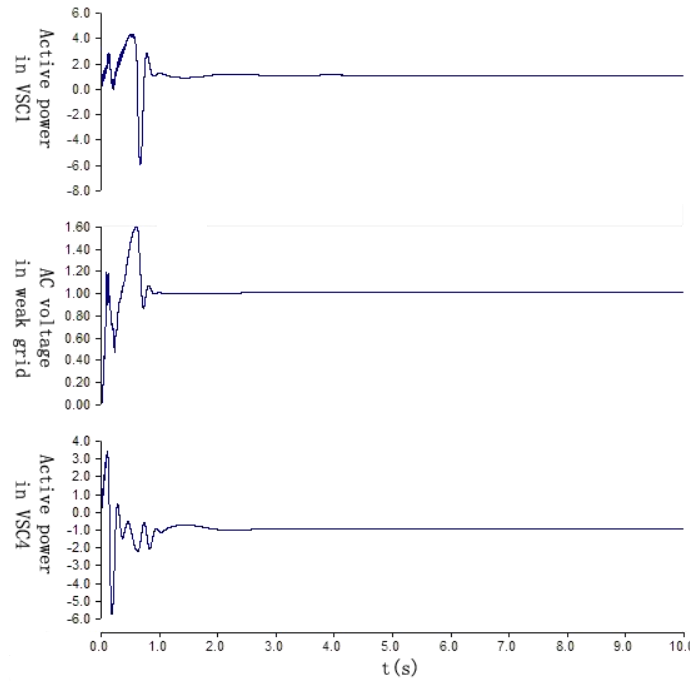


Fig. 6 Diagram of 1st control strategy start-up

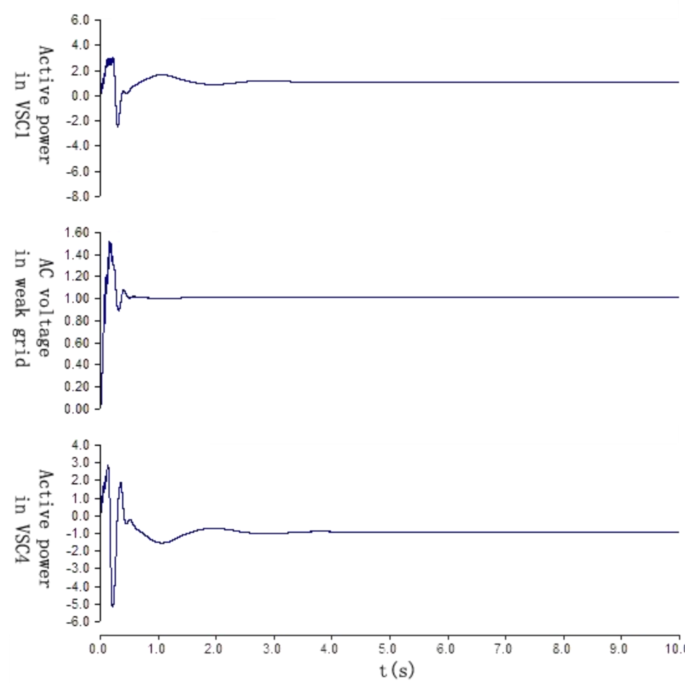


Fig. 7 Diagram of 2nd control strategy start-up

Comparing fig.8 with fig.9, after the model using overvoltage control, the overshoot of DC line Ⅰ voltage decreases from 1.55

to 1.1 and the overshoot of DC line Ⅱ decreases from 1.86 to 1.1. Also, the over-current is depressed when the capacitance is being charged, which can be seen from the active power overshoot diminishing when the system is in start-up stage. The effectiveness and feasibility of overvoltage control are verified.

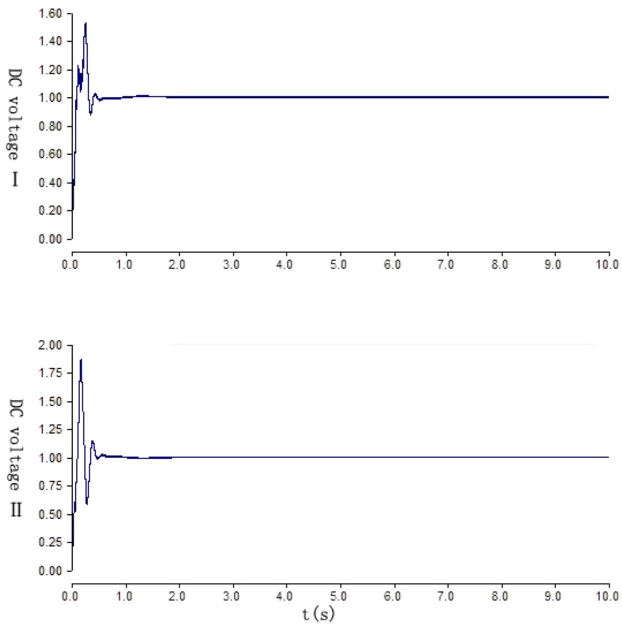


Fig. 8 Diagram of DC voltage without overvoltage control

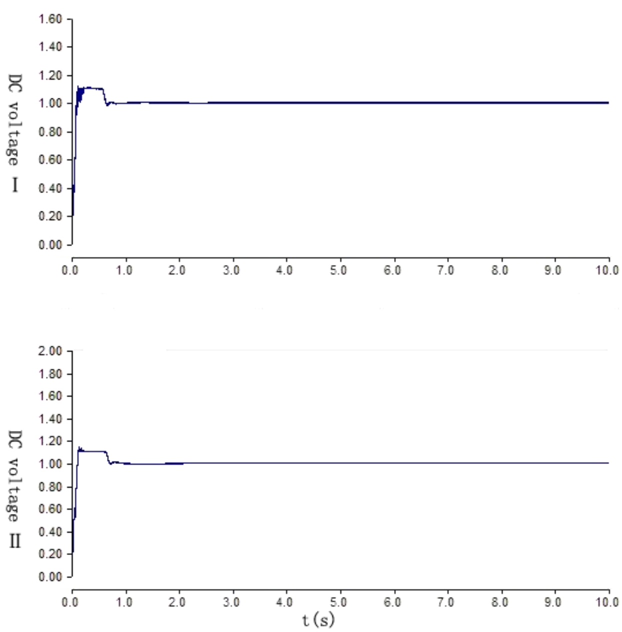


Fig. 9 Diagram of DC voltage with overvoltage control

From fig.10, we can see that the overshoot of AC voltage is also decreased. By applying the overvoltage control, not only the overvoltage in 1st layer control diminishes and the oscillations decreases in active power, but also the overshoot of AC voltage in weak grid is decreased. It means that the overvoltage of DC voltage has interaction with the overvoltage of AC voltage of weak grid.

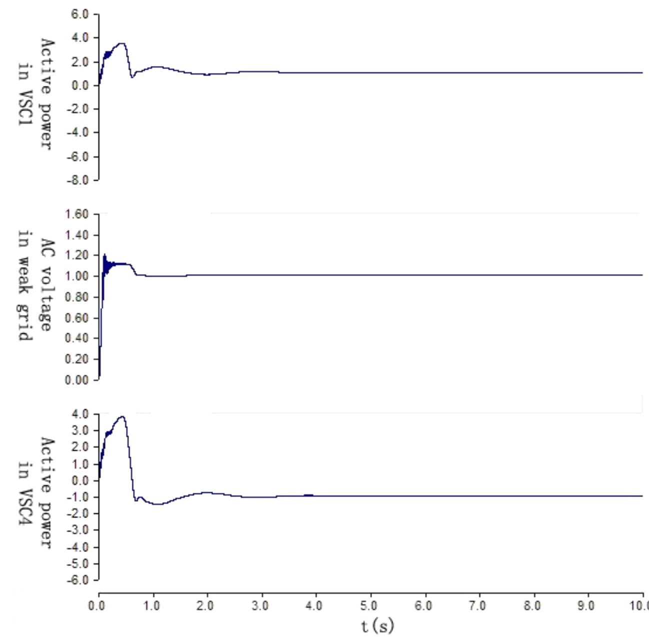


Fig. 10 Diagram of active power and AC voltage with overvoltage control

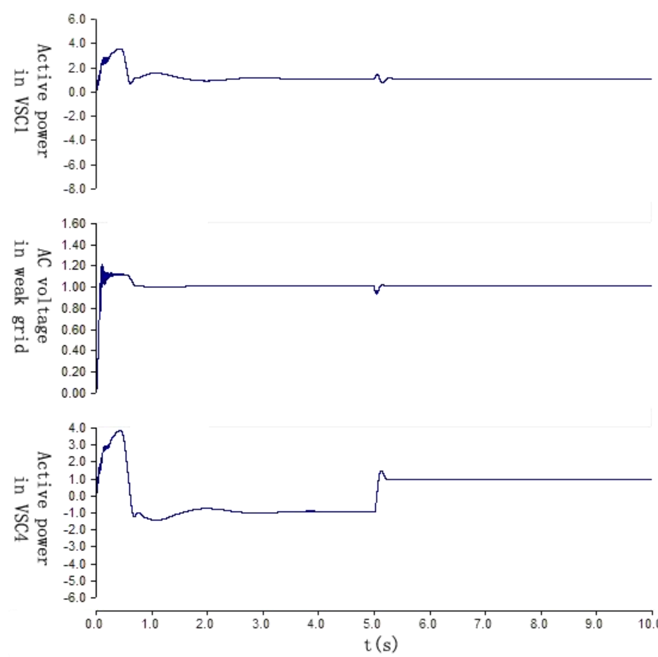


Fig. 11 Diagram of step response in AC load

Fig.11 shows that a step response is simulated. The load in weak AC grid increased to twice as much as VSC2 rated power. The VSC1 and VSC2 keep the original rated active power and the VSC3 and VSC4 reverse the active power flow. The power flows from VSC4 to VSC3 immediately. The dynamic response of the power reversing is steady and fast. It shows the hierarchical

control has correctness and practicability in the model simulated in this paper.
All in all, hierarchical control presented in this paper can be used to supply power to weak AC grid in the VSC based DC grid. And the whole system can have a good dynamic response.

## 4 Conclusions

Based on the research on the study of weak AC grid integrated in VSC based DC grid, a hierarchical control has been proposed in this paper. Regardless of the topology of DC grid, this method only takes into account the number of VSCs that exist in the link between the layer control and strong grid. The control methods in different layers have been discussed and the control variables in IP-VSC and EP-VSC have been investigated. The ability of dynamic response has been improved after adopting the hierarchical control in the model with 4 VSCs and 2 layers control.
It is concluded:
(1) A hierarchical control has been designed in this paper. The control strategy can make the weak AC grid running stably with some loads and make the weak AC grid to be a bridge connecting IP-VSC and EP-VSC.
(2) The hierarchical control proposed in this paper can make the weak AC system build a steady AC voltage rapidly, short the balancing time in the stage of start-up, so the whole DC grid has a good dynamic stability. The VSCs connected with the weak grid are divided into IP-VSC and EP-VSC by the direction of active power flow and then the control modes of the two VSCs are determined. The classification of the 2nd layer VSC is beneficial to the control of the whole system.
(3) When the load in the weak AC becomes larger, the flow of active power in DC line Ⅱ will reverse and a new steady state of the system can be built soon.

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